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FINAL REPORT ON EXPLORATION AND EVALUATION OF ALTERNATIVES FOR THE MK16 PRIMARY DISPLAY

Prepared for PEO-EOD

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Explosive ordnance divers using the MK16 Underwater Breathing Apparatus (UBA) must constantly monitor their primary display to ensure that safe oxygen levels are maintained in the breathing loop. Failure to do so can lead to hypoxia or hyperoxia. To use the new, hand-held UIS effectively, divers must concentrate on a large, information-filled screen for long periods. This distracts divers from adequately monitoring the primary, and compromises their safety. In this situation, the primary display information is simply "lost" due to visual overload from the UIS. There is a need to increase the diver's awareness of this important information. Analysis of alternative matrices was used to identify, evaluate, and rank candidate methods. Alternative methods were analyzed and scored (5 being the highest score, and 1 the lowest) based on human factors and hardware characteristics. Since even the best engineered hardware will not produce a viable system if the man-machine interface is not carefully considered, the analysis uses a hierarchical scoring method to place the most weight on the human factors aspects of the candidate methods. Scores were based on literature references and input from Navy Experimental Diving Unit's (NEDU) and Coastal Systems Station's (CSS) engineering personnel experienced in diving, diving system design and human factors as related to MK16 and UIS operations.

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PURPOSE

The purpose of this study is to report on alternative methods that will increase diver safety by raising their situational awareness of the information on the MK16 primary display while using the Underwater Imaging System (UIS), and in other mission scenarios.

BACKGROUND

Explosive ordnance divers using the MK16 Underwater Breathing Apparatus (UBA) must constantly monitor their primary display to ensure that safe oxygen levels are maintained in the breathing loop. Failure to do so can lead to hypoxia or hyperoxia. To use the new, hand-held UIS effectively, divers must concentrate on a large, information-filled screen for long periods. This distracts divers from adequately monitoring the primary, and compromises their safety. In this situation, the primary display information is simply "lost" due to visual overload from the UIS. There is a need to increase the diver's awareness of this important information.

METHODS

Analysis of alternative matrices was used to identify, evaluate, and rank candidate methods. Alternative methods were analyzed and scored (5 being the highest score, and 1 the lowest) based on human factors and hardware characteristics. Since even the best engineered hardware will not produce a viable system if the man-machine interface is not carefully considered, the analysis uses a hierarchical scoring method to place the most weight on the human factors aspects of the candidate methods. Scores were based on literature references and input from Navy Experimental Diving Unit's (NEDU) and Coastal Systems Station's (CSS) engineering personnel experienced in diving, diving system design and human factors as related to MK16 and UIS operations.

The analysis was divided into three sections, listed in order of importance: 1) sensory stimulus modality, 2) stimulus coding method, and 3) actuator characteristics. The individual actuator scores were summed and multiplied by the highest stimulus coding method score for the given actuator type, and then by the stimulus modality score to give a total score. Recommendations are based on the resulting scores.

ANALYSIS

SENSORY STIMULUS MODALITY

Each candidate represents a human stimulus sensory channel input. Olfactory modality was considered incompatible with the environment and task, therefore, not included in the analysis. Evaluation and scoring were based on referenced human factor criteria. Detection performance scores were based on the task of "attention getting." The environmental compatibility scoring assumed the diving environment, immersions, changing pressures, attention to mission, rich visual field, water-born background noise, possibility of cold dark water and diver dress.

The auditory bone conduction stimulus channel is a unique auditory channel in which the actuator transmits sound via bone conduction versus ear canal conduction. In the diving environment, this type of stimulus provides a unique modality that eliminates hearing problems associated with ear clearing and ear canal blockage. This communication method does not suffer the high loss of sensitivity in cold environments associated with cutaneous tactual modality. The dual-mode stimulus channels of auditory/visual (auditory bone conduction or auditory water borne) provide a significant increase in detectability over any single sensory stimulus modality.

Stimulus Channel	***Detection Performance***	***Environmental Compatibility***	***Score***	***References***
Auditory Bone Conduction (ABC)	4	4	8	Ref. 1, page 88
Visual (V)	3	3	6	Ref. 2, page 57
Tactual (T)	2	1	3	Ref. 1, page 327; Ref. 2, page 143
Dual-Mode AV	5	4	9	Ref. 2, page 54

Rating Key
5: Excellent
4: Very Good
3: Good
2: Fair
1: Marginal

STIMULUS CODING METHODS

Stimulus coding methods represent the way information is carried through the sensory channel. It is the characteristic of the signal detected by the human receptor nerves. The candidate coding methods were scored on their relative detection performance for a vigilance task in the diving environment. System performance is highly dependent on actuator selection. Under each stimulus coding method, only viable candidate actuators were considered. For example, the requirement for low magnetic signature excluded magnetic actuators as candidates. Light emitting diodes' (LEDs) superiority over other visual actuators in this application made them the obvious choice.

Auditory Bone Conduction Coding Method	***Actuator***	***Score***	***References***
Pure Tones	Piezo	4	Ref. 1, page 141 Ref. 2, page 136
Pulse/Burst	Piezo	2	
Intensity (INT)	Piezo	3	
INT/Tones	Piezo	5	

Visual Coding Method	***Actuator***	***Score***	***References***
Color	LED	3	Ref. 1, page 141 Ref. 2, pages 82-83
Intensity	LED	2	
Flash Rate	LED	3	
Color/Flash Rate	LED	4	

Tactual Coding Method	***Actuator***	***Score***	***References***
Vibration	Piezo, air, hydraulic	2	Ref. 1, page 327 Ref. 2, page 143 Ref. 3; Ref. 4; Ref. 5; Ref. 6; Ref. 7
Push/Pull	Piezo, air, hydraulic	3	
Pin Prick	Piezo, air, hydraulic	1	
Electrical Current	Electrodes	2	
Thermal (Heating)	Resistive heater	1	

<u>Rating Key</u>
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ACTUATOR CHARACTERISTICS

The actuators were evaluated on an engineering basis taking into account the task and the diving environment. The category score for each actuator was summed for a total actuator score.

Actuator	***Stimulus Modality***	***Fail Safe***	***Low μ Signature***	***Low Acoustic Signature***	***Reliability***	***Rig Impact***	***Encumbrance***	***System Complexity***	***Low Power Requirements***	***Environment Compatibility***	***Supportability***	***Technical Maturity***	***Cost***	**Total Actuator Score**
Auditory Bone Conduction Piezo	ABC	3	4	4	5	4	4	4	5	4	4	4	4	49
LED	V	5	4	5	5	5	5	5	4	3	5	5	5	56
Tactor Piezo	T	2	3	2	3	3	3	3	2	3	4	2	3	33
Tactor Air	T	2	3	2	2	2	3	2	2	2	3	3	3	29
Tactor Hydraulic	T	2	3	3	3	2	3	3	2	2	3	2	2	30
Electrodes	T	2	3	5	2	4	2	2	5	2	3	3	4	37
Resistive Heater	T	2	3	5	4	4	3	3	2	2	4	4	4	40

Rating Key
5: Excellent
4: Very Good
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FINAL SCORE AND CONCLUSIONS

The final method scores were calculated by multiplying the total actuator score by the coding method score (highest score for given actuator type) and the stimulus modality score. Auditory bone conduction stimulus modality provides the best sensory channel in an environment that requires vigilance, particularly in an environment rich in visual stimulation, as during sound navigation and ranging (SONAR) operation. Visual modality provides a fail-safe element not available in other sensory stimulation channels without subjecting the diver to an annoying constant stimulation. A combination of auditory bone conduction and visual stimulus provides the best warning system. Tactual modality suffers from a number of shortcomings including variable thresholds, repeatability and actuator placement sensitivity. These weaknesses are compounded when employed in a cold environment, which is often the case in diving operations.

Actuator	***Total Actuator Score***	***Coding Method x Factor***	***Stimulus Modality x Factor***	**Total System Score**
Auditory Bone Conduction Piezo	49	5	8	1960
LED	56	4	6	1344
Tactor Piezo	33	3	3	297
Tactor Air	29	3	3	261
Tactor Hydraulic	30	3	3	270
Electrodes	37	2	3	222
Resistive Heater	40	1	3	120

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RECOMMENDATION

Combining an auditory bone conduction warning system with the existing visual primary display would provide a significant rig safety enhancement for both SONAR as well as normal operations. Auditory bone conduction stimulus modality provides the best single channel of communication for warning systems. Detectability is further improved when an auditory stimulus is combined with a visual stimulus. Adding an auditory alarm to the existing visual primary display will have minimal impact on the rig and will provide a viable warning system, with the existing display providing the fail-safe element. The input for the audible alarm can easily be tapped off the rig's primary display output connector in series with the primary display whip. A small waterproof control module could contain alarm logic, actuator driver and a small battery if an auxiliary power source is needed. The power efficiency of piezo-electric audio actuators may allow the alarm system to be powered from the rig's existing battery without a significant impact on operation time. A small water blocked cable whip would connect the control module to a piezo actuator, which is placed behind the diver's ear on the mastoid bone. The actuator can be positioned and held in place in a small pocket incorporated in or on the diver's mask strap.

A fixed delay can be programmed into the system to avoid nuisance alarms while the rig is in normal operation, adjusting ppO_2 for water column changes. The auditory alarm coding method can be kept simple since it only needs to alert the diver. Any attempt to code the primary display information onto the auditory channel would increase diver sensory load and would require additional training. System complexity would also increase. The auditory bone conduction alarm should be a single tone stimulus in the range of 500 Hz to 1 kHz and would be easily implemented[3]. Actual frequency selection must take into consideration interference from or with the operational environment and any other diver-worn equipment. The piezo actuator and necessary audio levels have been proven to meet magnetic and acoustic level specifications for ordnance rated UBAs during tests for the EX19. The proposed system incorporates existing components and proven technology developed for the EX19, resulting in reduced cost, development time and project failure risk.

The greatest design risk factor is the determination of the alarm activation algorithm logic. As the complexity of the logic grows, the system complexity also grows and if this logic is subject to change, some degree of programmability will need to be designed into the system. Considerable deliberation will be required to ensure a safe and effective alarm, while avoiding nuisance alarms.

REFERENCES

1. Cushman, W. H.; Rosenberg, D. J. Human factors in product design. The Netherlands: Elsevier Science Publishers B.V.; 1991. p. 88, 327, 141.

2. McCormick, E. J.; Sanders, M. S. Human factors in engineering and design. 5th ed. McGraw-Hill Book Company; 1982. p. 57, 143, 54, 136, 82-83.

3. **ibid**. p. 136.

4. Discussions with Mr. Rich Roesch, Human Factors Engineer and a MK16 qualified diver with Coastal Systems Station. Mr. Roesch is a consulting engineer for EOD on the Integrated Navigation SONAR System (INSS) and UIS hand-held SONARs. He provided human factors guidance based on his first-hand operational experiences while diving the INSS. Date of discussions: 1 May 00.

5. Discussion with Mr. Joel Peak, Electrical Engineer and Project Manager for the Tactual Situational Awareness System (TSAS) program. The TSAS is a product improvement program (PIP) for the UIS/INSS program. Mr. Peak provided guidance on tactual stimulus based on the results of more than a year of research, design and manned testing of tactual actuators for use in the INSS/UIS diving and other environments. Date of discussion: 17 April 00.

6. Discussion with Mr. Jon Munday, PEO-EOD. Discussion centered on MK16 operational procedures maintenance and supportability. Also, SPECWAR primary option. Date of discussion: 17 April 00.

7. Discussion with Mr. Peter Ready, Steam Machines, Inc. Discussion centered on application and configuration of bone conduction actuator. Date of discussion: 21 April 00.

8. Discussion with Mr. Paul Browne, Steadfast Technologies. Discussion centered on application and configuration of various tactual actuators. Date of discussion: 3 April 00.

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APPENDIX A

ALTERNATIVE SOLUTIONS

POSSIBLE SHORT-TERM SOLUTION

A possible short-term solution was proposed incorporating the new SPECWAR wrist-worn primary display modification as a temporary, low-cost safety improvement. Wearing the display on the inside of the wrist might improve observation by placing the unit in the diver's direct field of vision when operating the SONAR. The engineering for the modification is completed and has been signed off by SPECWAR and forwarded to EOD/NAVSEA 00C for approval. The hardware for this modification is essentially a longer primary display cable that routes along the diver's arm and attaches to a display holder wrist strap. Mr. Richard Roesch felt this would not be a viable solution. His experience with the UIS proved the diver is already visually overloaded.

POSSIBLE SOLUTION IF COMPLEX LOGIC IS REQUIRED

Goal: Alert the diver when there is a problem with his rig so he will then check his primary or secondary display to get more information about the problem. Continue to provide fail-safe and informational capability via the existing primary display. The concept of alerting the diver to a problem versus providing repeated alarm information is described in the main report.

Requirements: This approach requires the use of a SONAR (e.g., INSS/UIS) or other diver equipment with processing and display capability. It also requires use of the existing MK16 primary display.

Concept: This concept makes use of the SONAR's inherent processing and display capabilities to decide when and how to visually alert the diver when a problem of sufficient severity occurs. Since the diver is fixated on the SONAR display (on board or mask mounted), a visual alert on this display is a prime candidate for getting his attention. The MK16 primary display signals, LEDs, would be input optically to the SONAR and the on-board processor would implement the logic necessary to determine when to put the desired visual alert on the SONAR display. This logic could be quite complex depending on several elements: primary display LED status, the amount of time the LEDs have been flashing, depth, rate of depth change, etc. The major benefit of this concept is to use the existing SONAR processing capability to implement the alert logic rather than building another programmable logic device to drive an alert element. In this case, the alert element is visual, but the same logic would also be required to drive auditory bone conduction elements. Visual alert possibilities are numerous ranging from subtle messages to whole screen alerts, and could even include

a repeater representation of the red/green primary display LEDs if desired. The existing primary alarm would remain in position on the mask so that the diver has the ability to continue to monitor his primary when not engaged with the SONAR.

Implementation: To implement this concept, an in-line connector would tap off the LED signals from the MK16 primary display whip and feed them to the SONAR. These signals would be optically coupled to the SONAR to 1) allow for easy underwater connection/disconnection, 2) electrically isolate the SONAR and the MK16, and 3) eliminate modifications to the SONAR housing. On the SONAR side, a whip comprising an optical coupler and two phototransistors would be plugged into an electrical connector on the SONAR housing. On the MK16 side, the signal tapped off the primary display would be used to drive two "repeater" LEDs that would optically couple to the SONAR phototransistors. The optically coupled connection would be designed so that the diver could easily break away from the SONAR should the need arise. Once the SONAR processor has the primary display signals, the new alert logic software would be used to determine when and how to alert the diver. The SONAR would be required to supply two digital inputs, power, and ground to an external connector.

Drawbacks: One drawback is that the diver must be physically coupled to a compatible SONAR in order to get the supplemental visual alert. This is why there is an emphasis on an optical connection designed to allow for easy underwater break away. Modification to the SONAR hardware/software is another drawback resulting from this approach. However, as the alert logic gets sufficiently complex and possibly even requires depth input, it becomes increasingly attractive to make use of the SONAR processing and display alert capabilities rather than building a new battery-powered programmable device to drive an additional alert element.

Note: The MK16 primary display itself could be used as the optical signal source for the connection to the SONAR. This would simplify the system, however, this means that the diver would have to be constantly monitoring the SONAR display to know the status of the primary LEDs.